Probing the Outflows of Supermassive Black Holes with Constellation-X

Presented by: George Chartas (Penn State)

In collaboration with: Niel Brandt(Penn State), Sarah Gallagher(MIT), Gordon Garmire(Penn State)

Premier : 5 May 2003

Movie Courtesy of NASA/HONEYWELL MAX-Q digital group/Dana Berry ©

Quasar Outflows

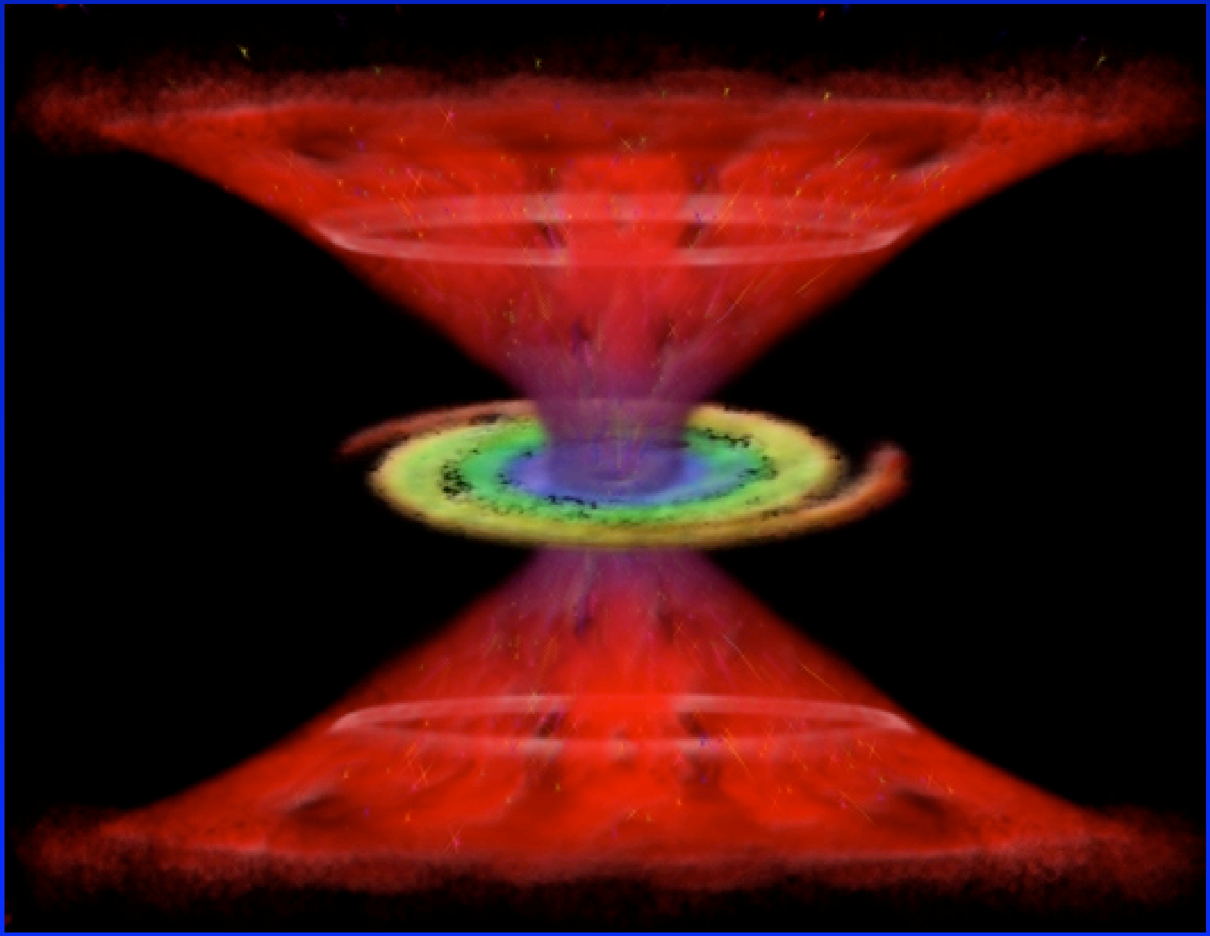


Image credit to CXC/M. Weiss

It is commonly accepted within the AGN community that most quasars contain high velocity winds of highly ionized gas flowing away from the central source at speeds ranging between 5,000 and 30,000 km s^{-1}

The Importance of Quasar Outflows

(a) Quasar outflows may distribute a significant amount of accretion-disk material into the interstellar and intergalactic medium.

(b) Quasar outflows may be important in regulating the coeval growth of black holes and their host galaxies (e.g., Fabian 1999)

(c) Quasar winds possibly provide a mechanism for angular momentum loss from the accretion disk

(d) It has been proposed that quasar outflows may be a source for cosmic dust (e.g., Elvis, 2002)

Unanswered Questions Regarding Quasar Outflows

(a) Is the X-ray absorption in BALQSOs due to the out-flowing wind? If so what are the kinematic properties of the X-ray absorbing medium?

(b) What are the ionization properties of the X-ray absorbers (N_H, n, U) and are they consistent with ionization properties of the UV absorber?

(c) Is the X-ray absorber the postulated shielding gas?

(d) Is the X-ray continuum from the primary source observed directly?

(e) Why is there a lack of variability in the velocity structures of UV BALs? (e.g., Barlow 1993; Proga et al. 1995) Is this true for X-ray BALs?

(f) Are low ionization BALQSOs quasars at an early stage in their evolution?

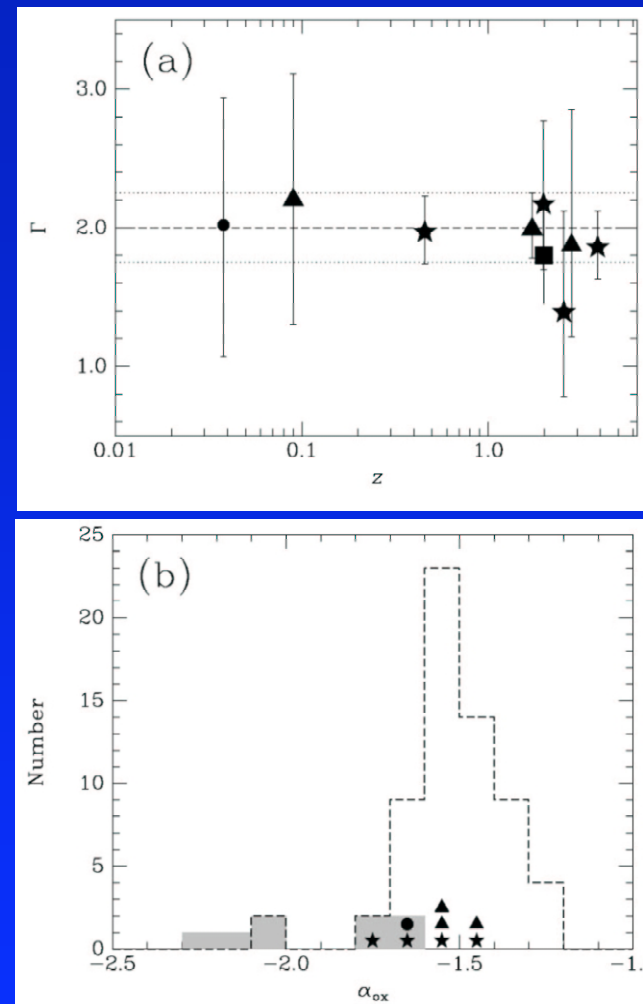
X-ray Observations of BALQSO's

- Present X-ray data for BALQSOs are sparse and only poor to moderate S/N spectra are available.

- X-ray faintness is likely due to absorption with N_H ranging from 10^{22} to 10^{24} cm^{-2} (Kopko, Turnshek, & Espey 1994; Green & Mathur 1996; Gallagher et al. 1999; Mathur et al. 2000)

- Their power-law continua are typical of normal quasars, with $\Gamma \sim 2$, and α_{ox} ranging from -1.70 to -1.44

- A subset of BAL quasars that contain low ionization lines such as Mg II, Al III, Fe II, and Fe III appear to be Compton-thick to radiation from the central source and only scattered X-rays are observed.



Triangle=miniBAL, star=BAL, circle=NLS1 PG1535+545, square=Green et al. 2001, dotted histogram= BLW sample of low z PG QSOs

Figures from Gallagher et al. 2002

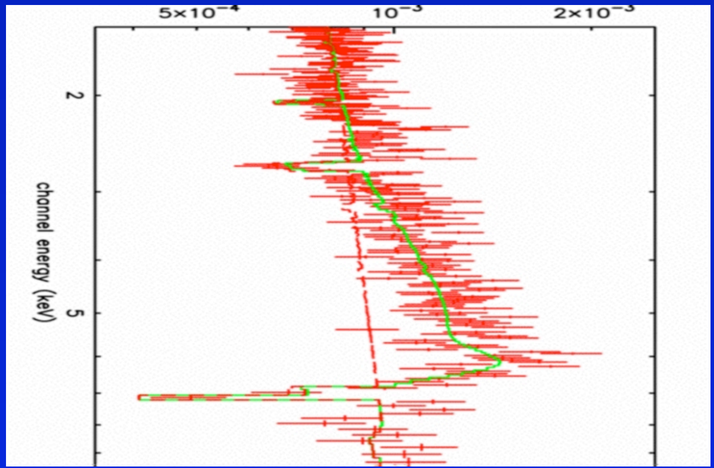
X-ray Observations of Ionized Outflows in AGN

- *XMM-Newton* and *Chandra* gratings observations of several AGN have revealed ionized absorbing material often outflowing from the central sources with velocities up to ~ 10^3 km s^{-1} (e.g., Sako et al. 2001; Kaspi et al. 2002)

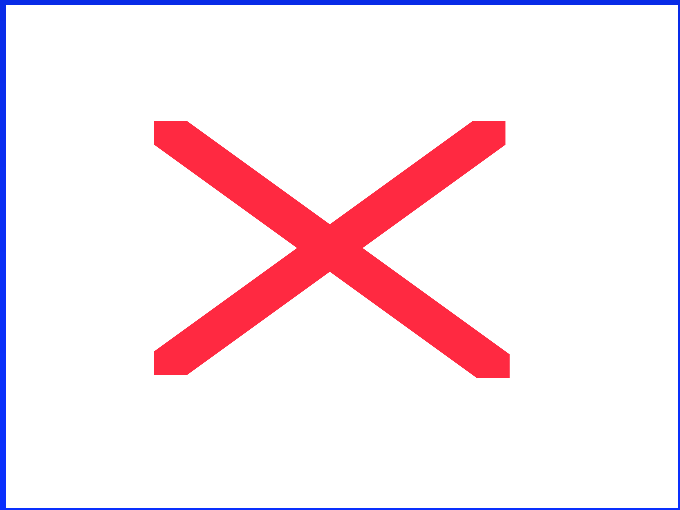
- The present gratings data indicate that the outflows consist of multiple components with different ionization levels and velocities.

- Temperatures of the ionized absorbing gas in Seyferts are $T \sim 10^5$ K. N_H range from 10^{21} cm^{-2} to 10^{22} cm^{-2}. The global covering factors of the X-ray absorbing outflows in Seyferts are ~ 50%.

- An *XMM-Newton* observation of the narrow emission line quasar PG 1211+143 shows absorption lines corresponding to the H- and He-like ions of Fe, S, Mg, Ne, O, N and C. The ionized absorber appears to be outflowing at a velocity of 0.08-0.1*c*. (Pounds et al. 2003, submitted to MNRAS)



RGS first order spectrum of IRAS13349+2438. Absorption lines in blue and red correspond to the low and high ξ component, respectively. (Sako et al. 2001, A&A, 365, L168.)



PN spectrum of PG 1211+143 showing Lyman alpha lines of Fe XXVI and S XVI. (Pounds et al. submitted to MNRAS)

Probing the Kinematics of Quasar Winds In Gravitationally Lensed BALQSOs

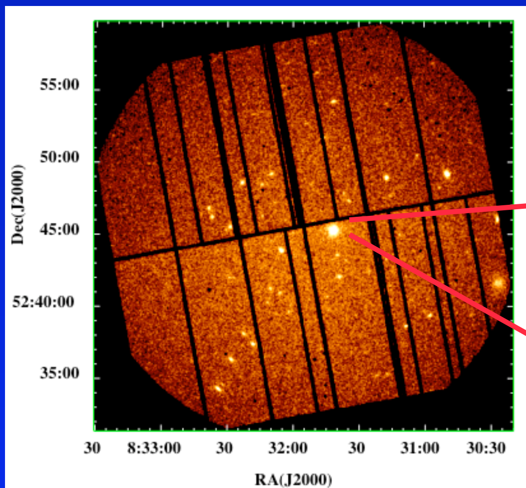
Probing the Kinematics of Quasar Winds

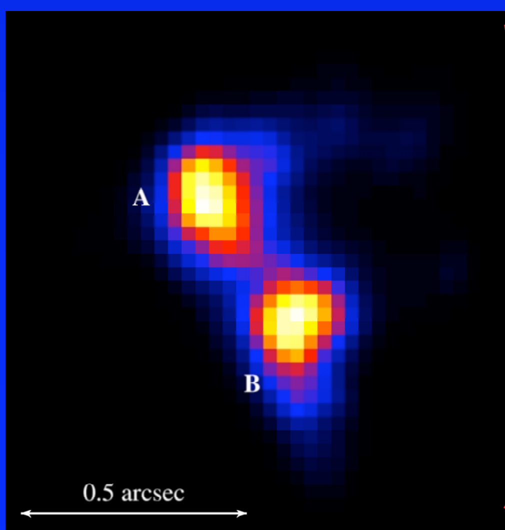
- Recent *XMM-Newton* and *Chandra* observations of the gravitationally lensed BALQSOs APM 08279+5255 and PG 1115+080 have provided insights into the structure of quasar outflows and the enrichment of the ISM and IGM by quasar winds.

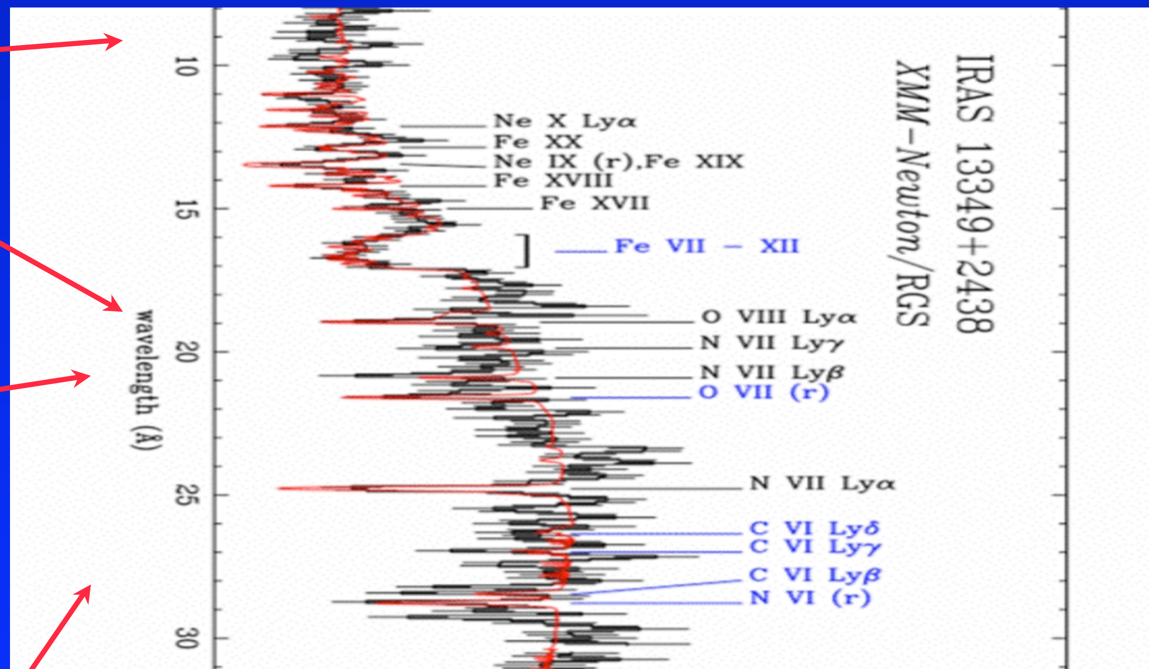
- APM 08279+5255 is a $z = 3.91$, IR luminous ($I = 14.55$) broad absorption line quasar with a maximum C IV wind velocity of ~12,400 km/s. Observed on 2002 Feb 24 for 89ks with *Chandra* and on 2002 April 28 for 100ks with *XMM-Newton*.

- PG 1115+080 ($z = 1.72$, $B = 16.1$) is a quadruply lensed BALQSO observed for 62.6ks on 2001 November 25 with XMM-Newton and observed with Chandra on 2000 June 2 for 26.8ks.

Probing the Kinematics of Quasar Winds in APM08279+5255

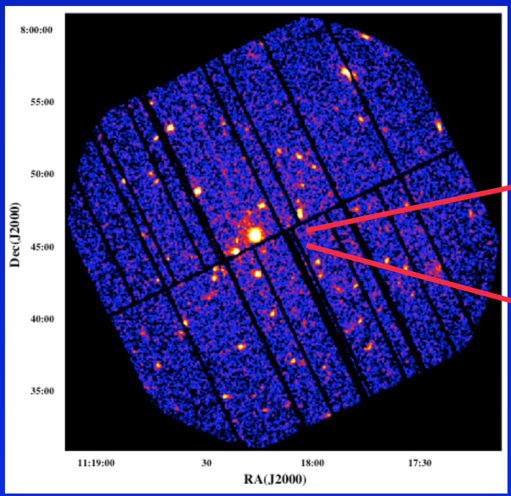


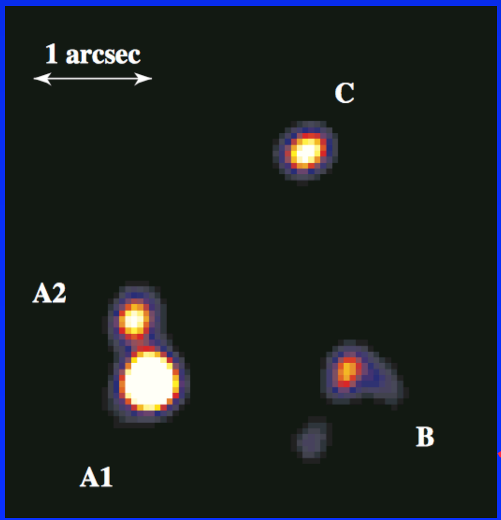


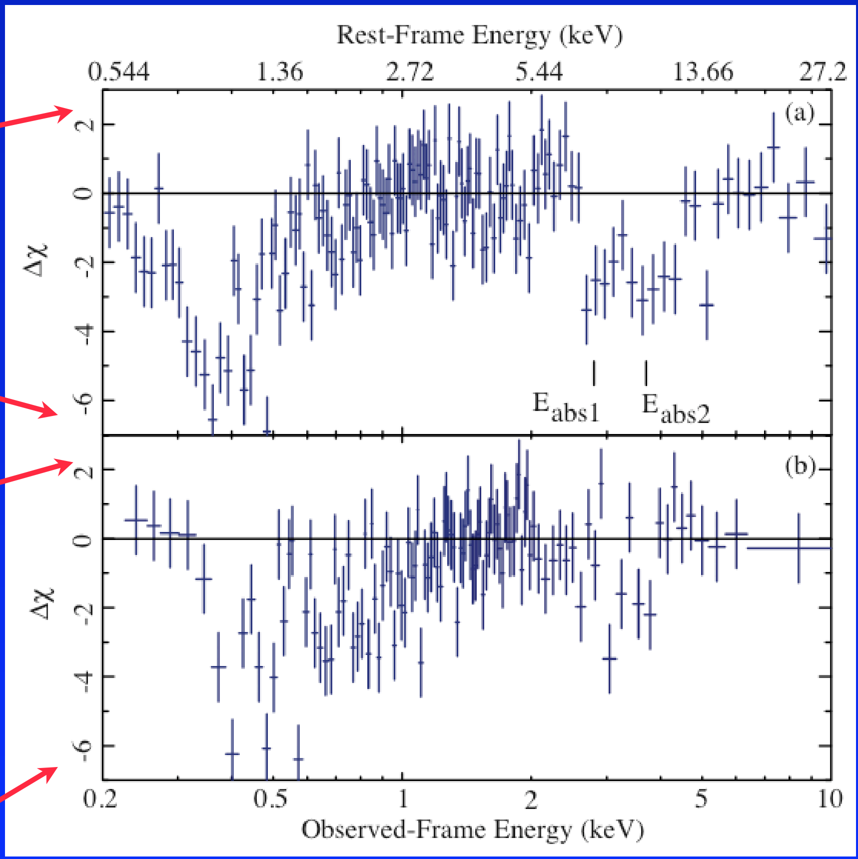


Blueshifted Fe XXV Kα absorption lines (a) XMM-Newton Spectrum (b) Chandra Spectrum of APM08279+5255. We find significant variability of the X-ray BALs on rest-frame timescale of 1.8 weeks.

Probing the Kinematics of Quasar Winds in PG 1115+080







Blueshifted Fe XXV Kα absorption lines (a) XMM-Newton Spectrum (b) Chandra Spectrum of PG 1115+080. We place a weak constraint on variability of the X-ray BALs on rest-frame timescale of 19 weeks.

Probing the Kinematics of Quasar Winds

Discussion of Spectral Results

- A plausible site that may be producing the absorption features is the quasar wind.

- We propose that the observed high-energy absorption lines are associated with Fe K resonant absorption.

- The rest energies of the most likely resonant absorption lines of Fe are:

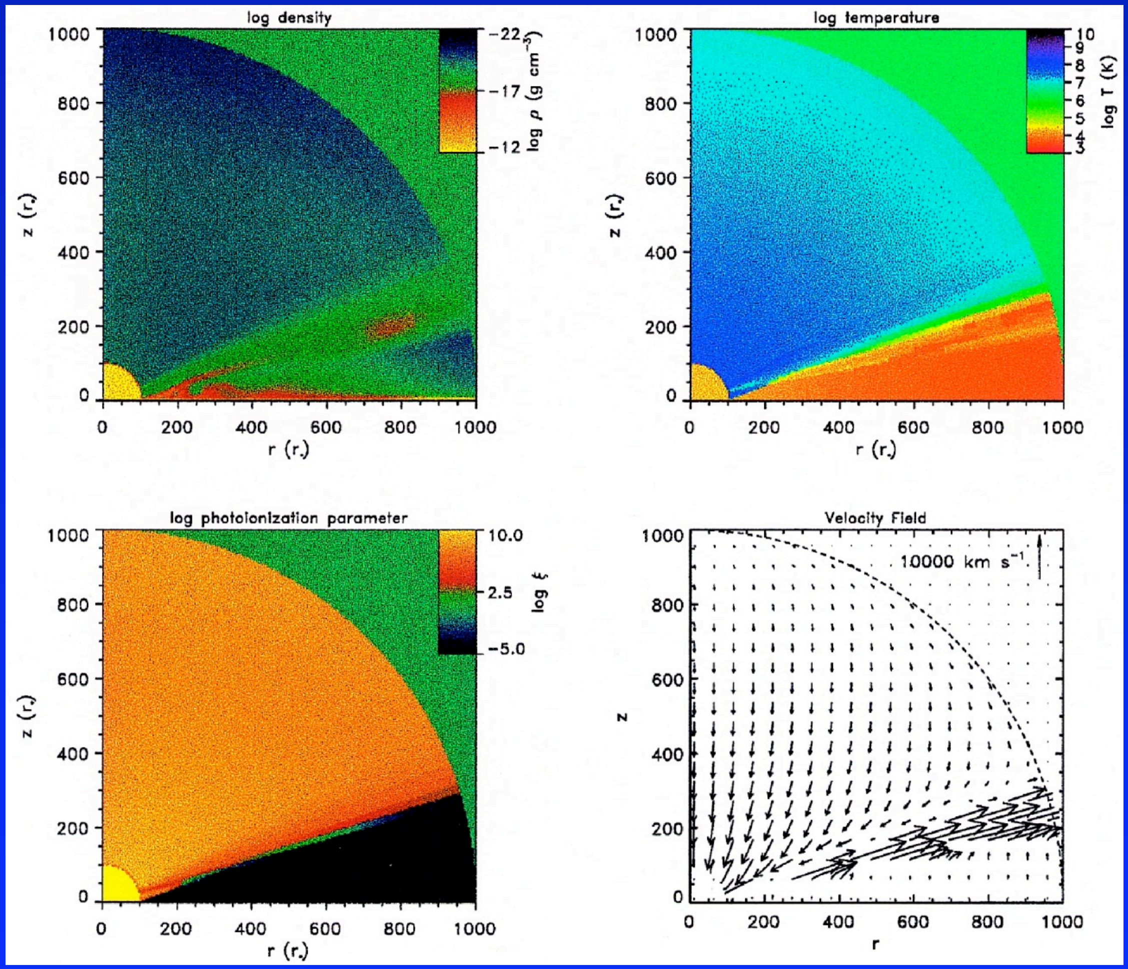
  6.70 keV (Fe XXV Kα), 7.88 keV (Fe XXV Kβ), 6.97 keV (Fe XXVI Kα), 8.25 keV (Fe XXVI Kβ)

  (Verner, D. A., Verner E. M., & Ferland, G. J., 1996, Atomic Nucl. Data)

- APM 08279+5255 : We estimate that the 8.05+/-0.1 keV and 9.79+/-0.2 keV absorption features correspond to wind velocities of 0.20c (Fe XXV Kα), 0.15c (Fe XXVI Kα), and 0.40c (Fe XXV Kα), 0.36c (Fe XXVI Kα), respectively.

- PG1115+080 : We estimate that the rest-frame energies of 7.38keV and 9.5keV imply outflow velocities of about 0.1c (Fe XXV Kα), 0.04c (Fe XXVI Kα), and 0.34c (Fe XXV Kα), 0.30c (Fe XXVI Kα), respectively.

Probing the Kinematics of Quasar Winds



Top left panel: Color density map of the AGN disk wind model. Top right panel: Color gas temperature map of the model. Bottom left panel: Color photoionization parameter map. Bottom right panel: Map of the velocity field (the poloidal component only). In all panels the rotation axis of the disk is along the left-hand vertical frame, while the midplane of the disk is along the lower horizontal frame.

Figure from Proga, Stone, & Kallman, 2000, ApJ, 543, 686

Probing the Kinematics of Quasar Winds

Simulations of mass outflows from quasar accretion disks. (Proga, Stone, & Kallman, 2000, ApJ, 543, 686)

Probing the Kinematics of Quasar Winds in APM08279+5255

Deriving a simplified wind velocity equation

The radiation force : $\frac{L}{4\pi r^2}\frac{\kappa m}{c}$

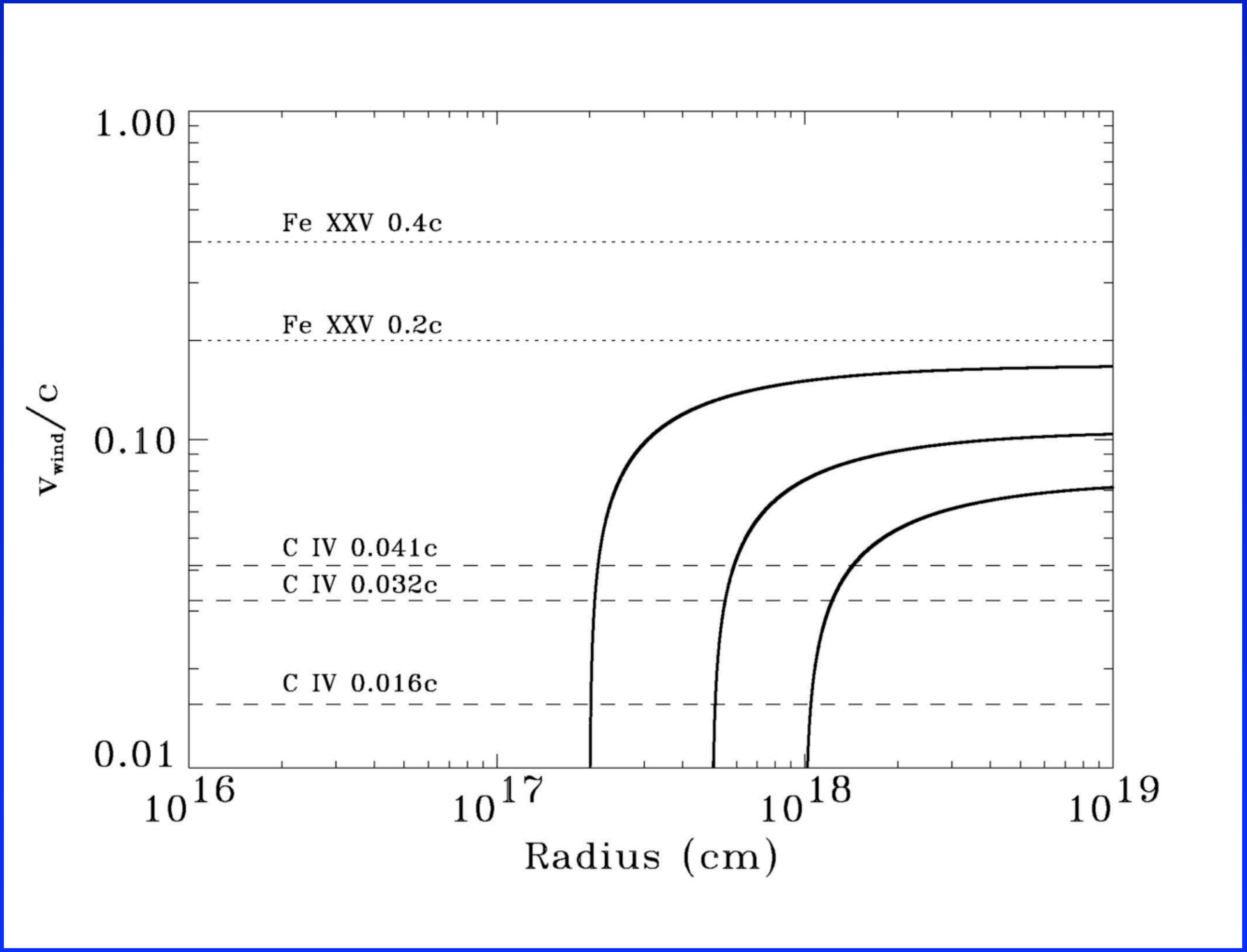
The (mass) x (radial acceleration) is given by : $mv\frac{\partial v}{\partial r} = \frac{L}{4\pi r^2}\frac{\kappa m}{c} - \frac{GM_{bh}m}{r^2}$

The velocity of the outflow at a radial distance R produced by radiation pressure from a central source with a UV luminosity of L_{UV} and a mass of M_{bh} at some radial distance R is :

$$v_{wind} = \left[2GM_{bh}\left(\Gamma_f \frac{L_{UV}}{L_{Edd}} - 1\right)\left(\frac{1}{R_{in}} - \frac{1}{R}\right)\right]^{1/2}$$

Where, L_{edd} is the Eddington luminosity, Γ_f is the force multiplier, R_{in} is the launching radius, and k is the mass absorption coefficient

Probing the Kinematics of Quasar Winds in APM08279+5255



Wind velocity as a function of radius from the central source for a radiation pressure driven wind. For a qualitative comparison we have estimated the wind velocities for launching radii of 2×10^{17} cm, 5×10^{17} cm, and 1×10^{18} cm. We have over-plotted the observed C iv BAL (dashed lines) and Fe xxv BAL (dotted lines) velocities. We have assumed Γ_f=100, L_{UV}=4x10^{46} erg/s, L_{Bol} = 2x10^{47} erg/s and L_{Bol}/L_{Edd} = 0.1.

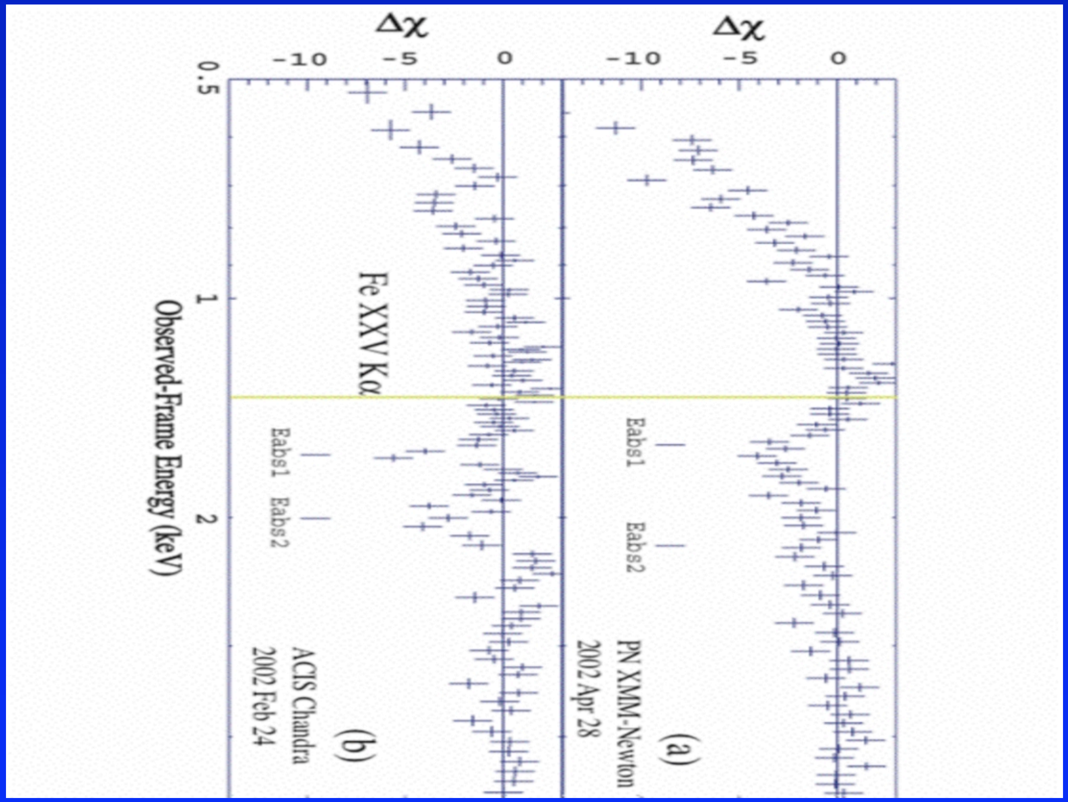
Probing the Kinematics of Quasar Winds in APM08279+5255

Mass-Outflow rate :

$$\dot{M} = 4\pi r\left(\frac{r}{dr}\right)N_H m_p v_{wind} f_c$$

$N_{FeXXVabs1} \sim 3.4\times10^{18}\,cm^{-2}$

$N_{FeXXVabs2} \sim 3.8\times10^{18}\,cm^{-2}$



Mass-outflow rate as a function of the distance to the absorber for r/dr ranging from 1-10, where dr is the thickness of the absorber. We assumed a hydrogen column density of $N_H=1\times10^{23}\ cm^{-2}$, a covering fraction of 0.2, and a wind velocity of 0.2c.

Probing the Kinematics of Quasar Winds in APM08279+5255

Constraining the location of the material making the X-ray BALs

Recombination time-scale of ionized wind:

$$t_{recomb} \sim 3 \times 10^4 Z^{-2}\ T_5^{\ 1/2}\ \ n_9^{-1}\ s$$

where $T=10^5 T_5$K is the electron temperature and $n=10^9 n_9$cm^{-3} is the electron number density.

Travel time for the gas to reach a certain distance from the launching radius:

$$t_{travel} = \int v_{wind}^{-1}\ dR$$

We find $t_{recomb} \ll t_{travel}$ suggesting that the X-ray BAL material is near the launching radius.

Assuming a range of electron number densities : 1×10^7 cm^{-3} to 1×10^{10} cm^{-3} we find the recombination timescale to range between 4.4×10^3 s and 4.4 s. For a launching radius of 2×10^{16}cm the amount of time needed for the radiatively driven wind to reach a distance of 5×10^{16} cm from the launching radius is $\sim4\times10^6$s.

Conclusions

- Discovery of the first X-ray BALs in the gravitationally lensed quasar APM08279+5255. Similar X-ray BALs detected in PG1115+080.

- The energies of the observed absorption features suggest the presence of X-ray BAL material outflowing from the central source at velocities of ~0.2*c* and ~0.4*c* for APM08279 and ~0.1*c* and ~0.34*c* for PG1115.

- The short recombination timescales for Fe XXV and Fe XXVI and the observed relativistic velocities suggest that the absorbers are launched interior to the minimum launching radius for UV BAL winds and may therefore represent the shielding gas proposed in several theoretical studies (e.g., Murray et al. 1995; Proga et al. 2000).

- The confirmation of relativistic outflows in most quasars would imply mass ejection rates significantly larger (factor of 10) than those based on the properties of UV BALs.

- We detected significant variability of the X-ray BALs on rest-frame timescales of 11days. This variability is consistent with our earlier conclusion of the location of the X-ray BAL material.

What Lies Ahead?

Observations of BALQSOs with *Constellation-X* will :

(a) Provide the higher energy resolution needed to resolve the complex structure of the X-ray BALs with short exposure times of about 10ks. In addition, monitoring of the X-ray BALs with *Constellation-X* on short timescales may allow us to track the acceleration phase of the absorbers via the velocity shifts of the resonant absorption lines.

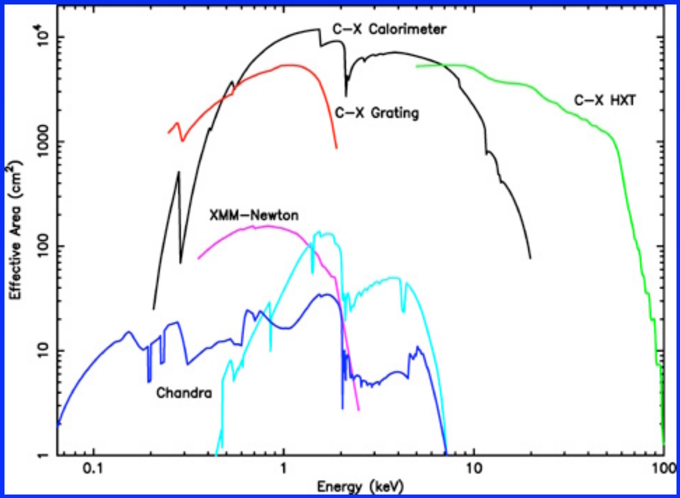
(b) Allow us to determine whether the flow is continuous or intermittent

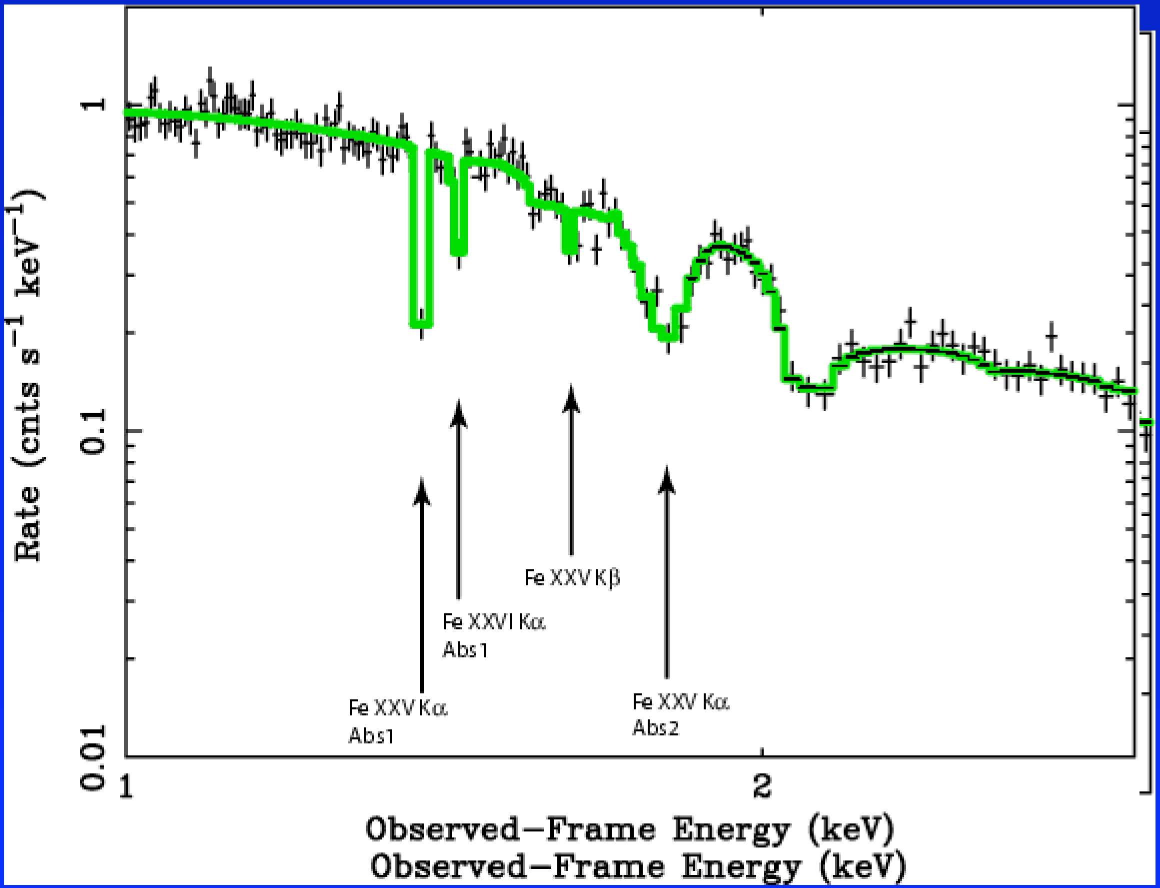
(c) Better constrain the kinematic, ionization and absorbing properties of the X-ray BAL material. (relative abundances of ion populations will constrain the ionization parameter)

(d) Provide input to MHD simulations of radiatively driven disk winds with the goal of better understanding the structure of quasars.

(e) Provide better constraints of the mass outflow rate in a large sample of quasars and ultimately allow us to estimate the contribution of quasar outflows to the enrichment of the ISM and IGM.

Simulated Constellation-X Calorimeter Spectra of Variable X-ray BALS in APM08279+5255





CREDITS

Director

George Chartas

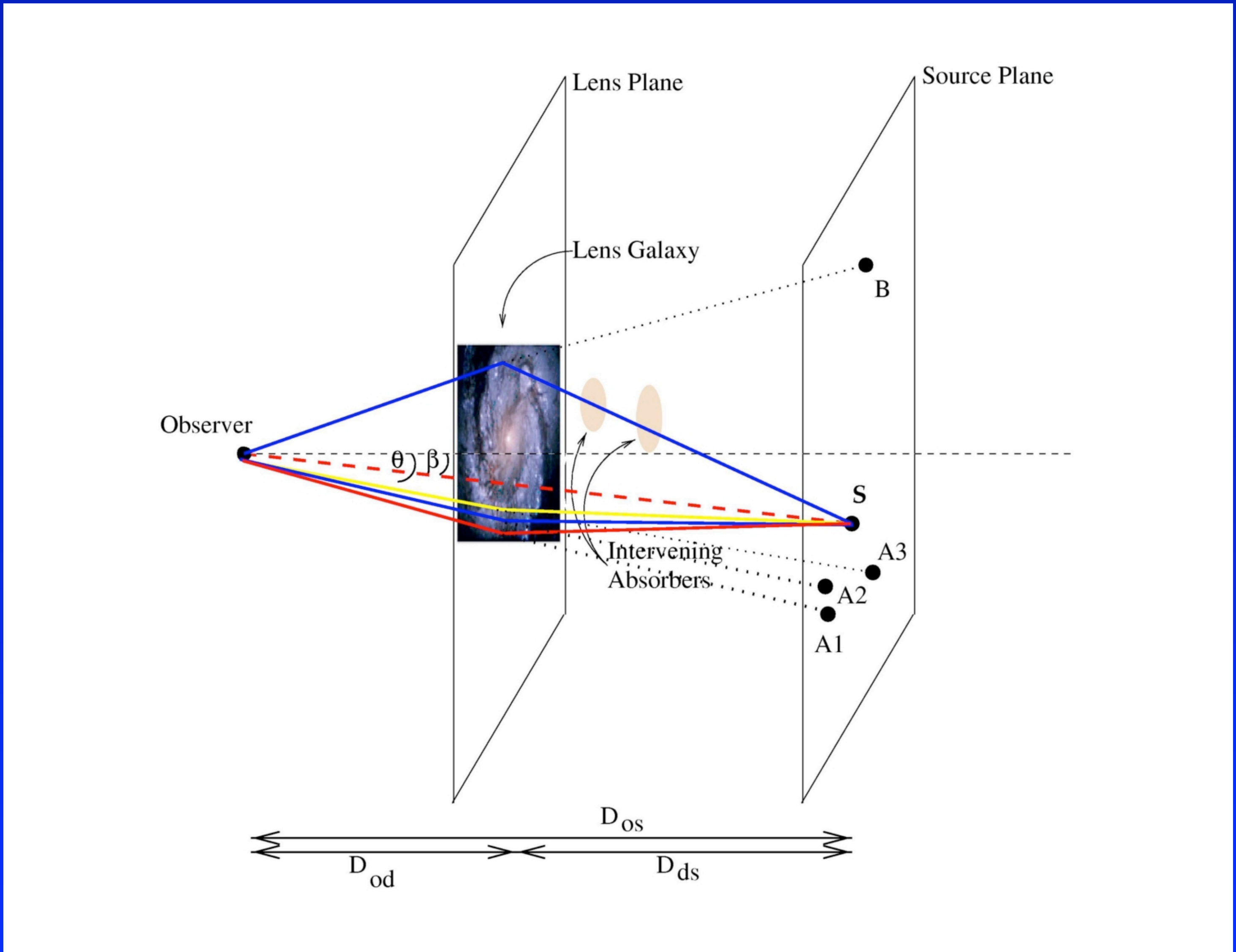
Actors

Niel Brandt

Sarah Gallagher

Digital Camera Personnel

Gordon Garmire



Conceptual diagram of the gravitational deflection of light in a quad GL system.

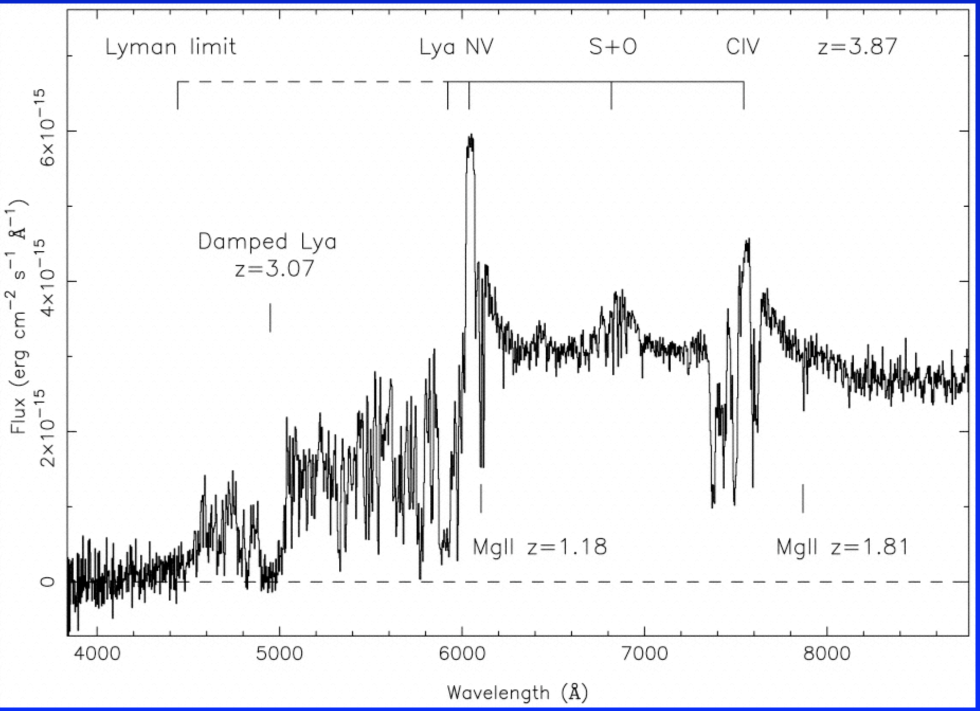
Probing the Kinematics of Quasar Winds in APM08279+5255

- Detailed analysis of the UV spectrum of APM 08279 (Irwin et al. 1998, Srianand & Petitjean 2000) show:

(a) Several associated narrow line systems from singly ionized species.

(b) Broad absorption line systems blueward of the high ionization emission lines of CIV, NV and OVI

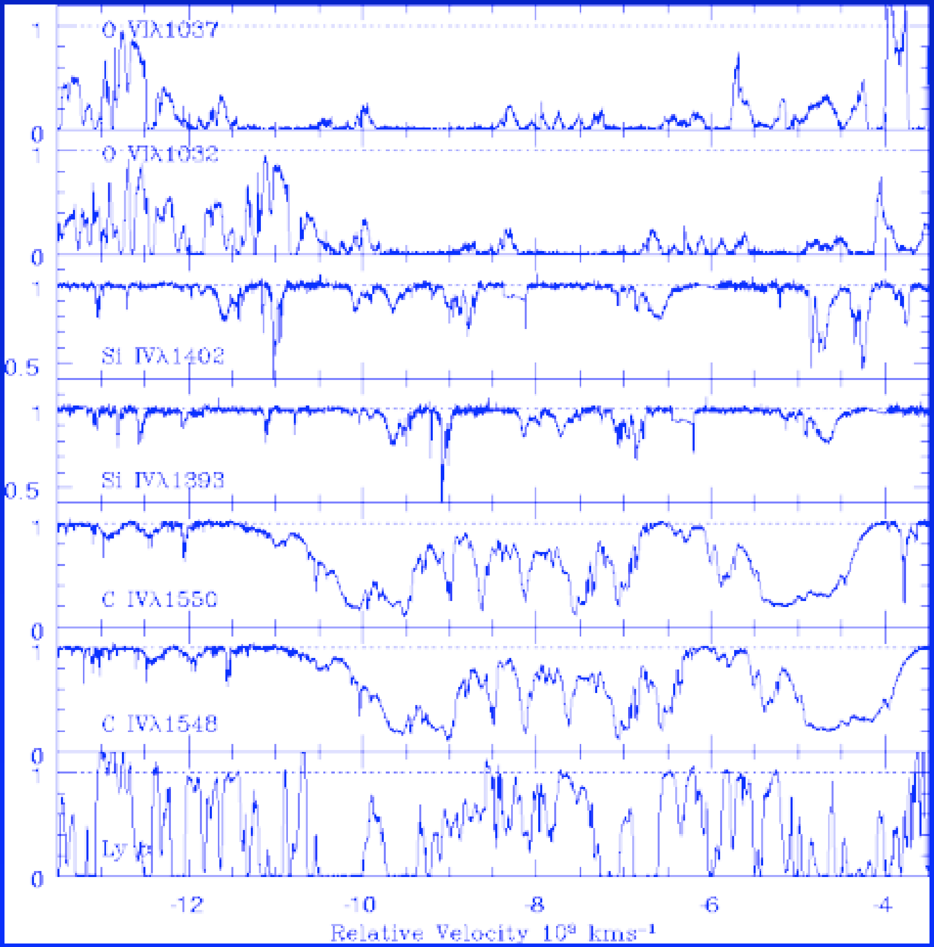
(c) Line locking may be present



Probing the Kinematics of Quasar Winds in APM08279+5255

(d) Multiple velocity components of CIV at ~ 4670 km s^{-1}, ~ 9670 km s^{-1}, and ~12,400 km s^{-1}

(e) The wide range of ionization levels, velocities and column densities inferred from the UV BALs imply that the wind may be composed of multiple regions of different densities, with large ionization gradients.

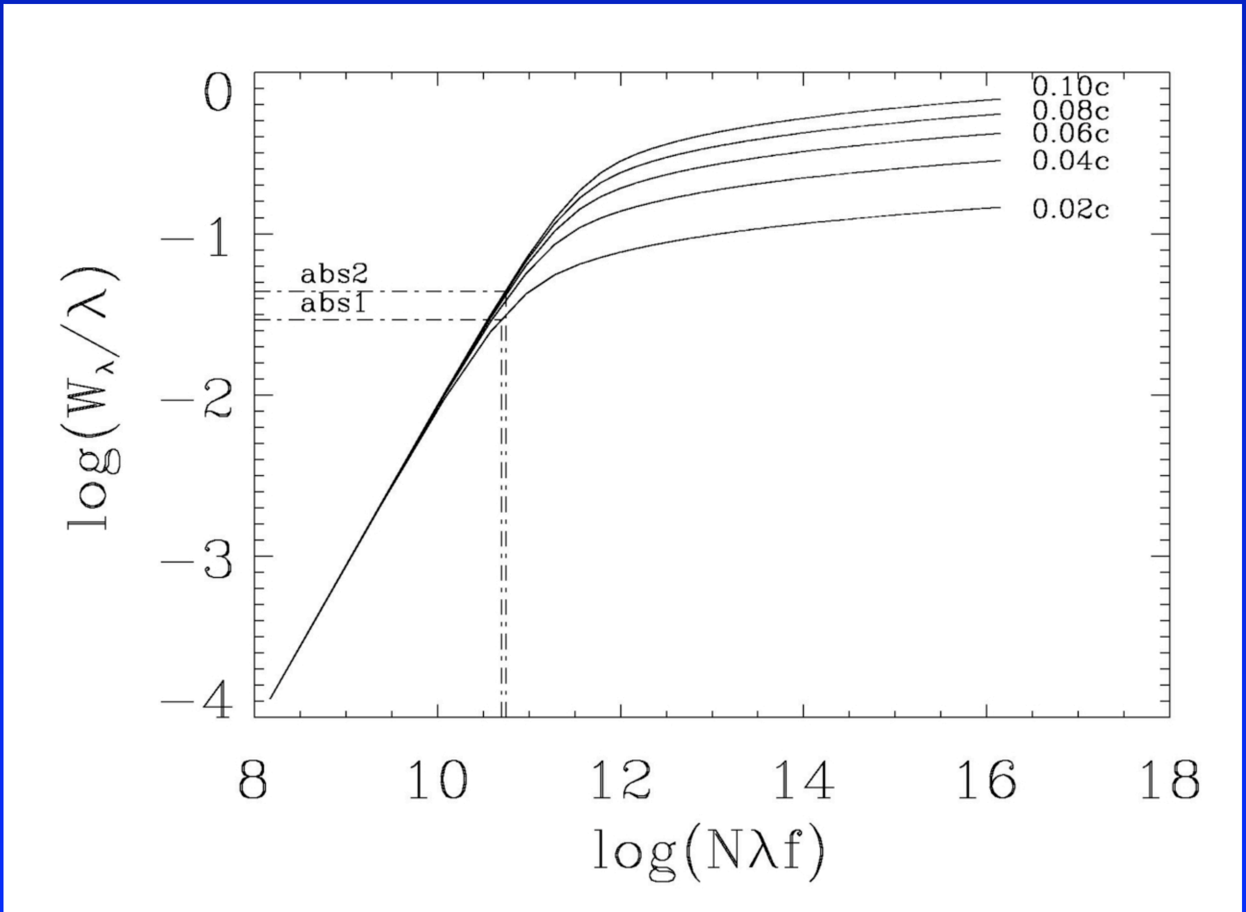


Searching For Black Holes

Probing the Kinematics of Quasar Winds in APM08279+5255

$N_{FeXXVabs1}$~ $3.4 \times 10^{18} cm^{-2}$

$N_{FeXXVabs2}$~ $3.8 \times 10^{18} cm^{-2}$



Using a curve of growth analysis we estimated the hydrogen column densities implied by the observed equivalent widths of the two absorption lines at 8.05 and 9.79 keV.
We assumed that the ion species responsible for the X-ray BALs is Fe XXV and *b* parameters of the order of the observed widths of the lines ($b = \sqrt{2}\sigma_u$).